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ABSTRACT

The application of polyvinyl acetate (PVA) was assessed as a potential protective edible coating in round-type tomato fruit (*Lycopersicum esculentum Mill*, cv. Gabriela) at the green stage of maturity. Coated and uncoated fruits were stored at ambient (20 °C, 40 % relative humidity, RH) and controlled (21 °C, 60 % RH) conditions during seven and 14 days and the effects on color, luminosity, weight loss, firmness, °Brix, vitamin C and respiration rate were studied. The polymeric coating did not significantly affect brightness, weight loss, and RR; however, environmental conditions at which the fruits were maintained had significant effects. Despite the statistically non-significant effects, our results showed that PVA coating was associated with slight protection of the fruit compared to uncoated fruits. This outcome is encouraging but suggests that more research is needed to consider these facts and control others that might be important in fruit ripening, such as molecular weight of the PVA, uniformity and thickness of PVA application.

ADDITIONAL KEY WORDS: *Lycopersicum esculentum*, edible films, polyvinyl acetate, tomato, shelf life.

ACETATO DE POLIVINILO COMO RECUBRIMIENTO COMESTIBLE PARA FRUTAS. EFECTO EN CARÁCTERÍSTICAS FISIOLÓGICAS Y DE CALIDAD EN TOMATE

RESUMEN

El acetato de polivinilo (PVA) fue estudiado como recubrimiento comestible protector y de alto brillo en tomate bola (*Lycopersicum esculentum* Mill, cv. Gabriela) en la etapa no madura del fruto. Los frutos cubiertos y no cubiertos se almacenaron en condiciones ambientales (20 °C, 40 % de humedad relativa RH) y en condiciones controladas (21 °C, 60 % RH) durante siete y 14 días y fueron estudiados los efectos en brillo, pérdida de peso, firmeza, °Brix, vitamina C y tasa de respiración. La cubierta polimérica no produjo un efecto significativo, sin embargo, las condiciones ambientales en las cuales se mantuvieron los frutos sí afectaron significativamente la respuesta de los tomates. A pesar de la no significancia estadística, nuestros resultados revelan que la cubierta protege levemente los frutos comparado con frutos no cubiertos. Este resultado es alentador pero indica que se requiere de mayor investigación, pues deben considerarse para estudios posteriores otros factores como el peso molecular del PVA, la uniformidad y el grosor de la cubierta aplicada.

PALABRAS CLAVE ADICIONALES: *Lycopersicum esculentum*, cubiertas plásticas comestibles, acetato de polivinilo, vida de anaquel.

INTRODUCTION

Food production and preservation is an important social issue of increasing concern in developing countries that has forced the allocation of more research efforts to investigate the preservation of fresh fruits. Tomato (*Lycopersicon esculentum* Mill) fruit is an important commodity worldwide for both the fresh and the processing markets, and it is within the second largest group of vegetables grown, playing a key role in human diet (Wold, 2004). Tomato is one of the most important Mexican horticultural exports to the United States (US) and the European Union, accounting for 38 % of the total Mexican export value of fresh vegetables to the US in 2003 (Wiesner, 2003). Nevertheless, shipping problems, including inadequate handling processes, reduce its quality and shelf life (Ergun *et al*., 2006). To optimize

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commercialization of fresh-market, round-type tomato growers have to minimize handling injury and maximize postharvest life.

Some methods used to extend the postharvest life of fruits and vegetables are based on retarding or diminishing the metabolic processes using low temperatures. However, tomatoes are often shipped at temperatures lower than the recommended 12.5 °C, which can induce chilling injury at any ripening stage (Maul *et al*., 2000). The use of artificial barriers, such as edible films, is another technique that could provide an excellent tool to extend tomato fruits quality by regulating diffusion of gases and minimizing physiological and pathological disorders at low cost (Troncoso-Rojas *et al*., 2005).

There are few reports in the literature concerning the application of synthetic polymeric coatings on fruits. Fisher, De Jonge and Christoffel (1967) developed a coating for fruits that increased attractiveness and preserved them from weight loss as well as from the attack of fungal or other infectious microbes. The application consists in fruits being coated by a solution of poly vinyl acetate (PVA) containing a substance that has fungicide and/or fungistat properties. The coating is effective for fruits and has additional advantages over other methods, in which the fruit was either coated with wax or wrapped in biphenyl-treated paper. Infections by *Penicillium*, or rind pitting, in PVA coated fruits is comparable to that of wax treated oranges, pineapples, avocados, and potatoes.

PVA is a non–toxic commercially important polymer prepared through emulsion polymerization which has been investigated as a coating film containing fungicides for protection of diverse foods and as a coating for pharmaceutical products, as reported by Hagenmaier and Grohmann (1999; 2000). The same authors reported that PVA with a minimum molecular weight of 2000 Da has been approved by the US Food and Drug Administration as a direct food additive in chewing gum base and many other food related applications. These reports suggest that PVA represents no risk for human health within the limits and specifications established for such applications. Hagenmaier and Grohmann (1999; 2000) reviewed the applications of PVA in food and pharmaceutical products for human consumption and even though there have been many studies addressing its use in these industries, PVA is not used commercially as a food coating.

Other natural coatings have been used for fruit coating on tomatoes. Tasdelen and Bayindirli (1998) coated tomatoes with Semperfreshedible (SEFE) fruit coating (composed of sucrose esters of fatty acids, sodium carboxymethyl cellulose and mono-diglycerides of fatty acids) and studied some quality characteristics after storage at two temperatures. SEFE coating was found to be significantly effective at two storage air temperatures (23 and 12 °C) to delay changes in firmness, titratable acidity, pH, soluble solids, sugars, ascorbic acid and lycopene. SEFE coating reduced fruit weight loss as compared to fruit without coating, but the difference between coated and uncoated tomatoes was not significant. Zapata *et al*. (2008) reported the use of alginate (a gum extracted from the cell walls of brown algae) or zein (a class of prolamine protein found in maize) as edible coatings in tomato in order to maintain quality parameters during postharvest storage. Coated tomatoes showed lower respiration rate and ethylene production than the control fruits. In addition, the evolution of color and weight loss was significantly delayed (4-6 days on average) in coated tomatoes as compared to controls. Thereafter, ascorbic acid remained at much higher levels at the end of storage in treated than in control tomatoes. The authors concluded that coatings with natural gums were effective in preserving quality characteristics of coated tomatoes longer than the uncoated ones. Park *et al*. (1994) used corn zein as a coat on tomatoes and color, weight and firmness changes and sensory quality were compared to uncoated tomatoes during storage at 21 °C; corn-zein film delayed color change and loss of firmness and weight during storage.

Coating fruits with a synthetic edible polymer could be a low cost tool for preservation with additional benefits over natural products, such as the year-round availability of the polymer and the constant quality and stability of the film from batch to batch. The present report provides a brief description for the preparation of PVA nanolatex by micro emulsion (ME) polymerization and presents an experiment designed to determine the effect of coating with PVA on several physical and physiological parameters related to the postharvest quality of tomato fruits.

MATERIALS AND METHODS

Polymerization of vinyl acetate in micro emulsion

ME polymerization of vinyl acetate (VA) was based on a previously developed technique. VA was polymerized in oil-in-water ME with a 4 % initial concentration of VA and 0.97 % of bis-2-ethylhexil sodium sulfosuccinate. Potassium persulfate was used as initiator in a reaction that was conducted in a semi continuous manner at 60 °C. After reaching the maximum polymerization rate in batch operation (4 min of reaction), the addition of more VA was started until the desired final concentration of the polymer was reached (23 to 42 %) and the system was allowed to react for another hour. The nanolatex was stored in a closed jar until used for coating the tomato fruits.

The PVA nanolatex obtained by ME polymerization used for coating tomatoes had average particle diameters of 45 nm with a polydispersity of 1.19. The nanolatex obtained was of smaller size and with higher polymer content than that reported by Sosa *et al*. (2001) who obtained PVA particles with an average diameter of 70 nm and a polymer content of 30 %. The very small dimensions of the nanolatex particles prepared by ME polymerization could facilitate the coating of food products to extend their useful life with higher efficiency than when using an emulsion polymer with larger particles. Consequently, we consider that manufacturing PVA through ME polymerization has the potential to be used as an edible coating in fruits, vegetables and other type of foods.

Tomato coating with PVA and treatments applied

Tomato (*Lycopersicon esculentum* Mill. cv. Gabriela) fruits in green maturity stage were collected from a commercial plantation conduced under greenhouse conditions during the Spring-Summer of 2005. Color classification was conducted according to a visual scale (Ergun *et al*., 2006), as reported by the United States Department of Agriculture (USDA, 1975). Green tomatoes were selected by uniformity of color and size and free of any physical defects that could affect the results or mask the treatments effect. Fruits were washed and dried at room temperature and either stored at laboratory conditions (uncontrolled conditions, approximately 20 °C, 40 % RH) or in a ventilated bioclimatic chamber controlled at 21 °C and 60 % RH (controlled conditions). Controlled environment simulated commercial shelf storage of tomato fruits. The treatments applied were: coated under controlled conditions (CC); uncoated under controlled conditions (UC); coated under uncontrolled conditions (CU); uncoated under uncontrolled conditions (UU); each treatment was maintained for either seven or 14 days of storage. Fruits were coated by applying the PVA latex with a brush; coated tomatoes were allowed to dry under ambient laboratory conditions (approximately, 20 °C and 40 % relative humidity) and then subjected to either controlled or uncontrolled environments. Five fruits were used per treatment, one fruit per replication.

Analytical measurements

Parameters measured to determine the effect of PVA coating included color, luminosity, weight loss, firmness, total soluble solids, vitamin C and respiration rate. Color and luminosity (Mitcham *et al.*, 1996) were determined with a Minolta colorimeter (CR-300, Japan) previously calibrated with a reference white plate; three readings on each tomato were obtained and reported according to the international color system (CIE). Weight loss was determined by weighing the fruits on an Ohaus GT8000 digital scale (USA) at the beginning of the experiment and after seven and 14 days of storage. Weight loss ratio was determined as a function of initial weight and reported as percent. Firmness (Mitcham *et al.,* 1996) was assessed with an EFFEGI penetrometer (model FT011, Italy) having a flat probe of 8 mm diameter equivalent to 0.5 cm^2 to measure the force required to penetrate 0.5 mm. Total soluble solids (Mitcham *et al.,* 1996), expressed as °Brix, were determined with a manual refractometer (ATAGO model ATC-1E, Japan) according to USDA standards. Vitamin C concentration was determined by titration with the 1,6-dichloroindophenol technique (Dewanto *et al.*, 2002). Respiration rate (Gomez, and Camelo, 2002) was assessed in one fruit with an infrared gas analyzer (CO_2 / H_2O) IRGA LI-COR model 6262 (USA). Fruits were placed for 30 minutes in a glass jar of known volume. Next, CO_2 concentration inside the flask was automatically recorded every two minutes and the concentration recorded at 14, 16, and 18 min from the beginning of the test (CO_2 evolution was at steady state); the amount of CO_2 per kg of fruit per hour was used to calculate respiration rate ρCO_2(mL $CO_2 \cdot kg^{-1} \cdot h^{-1}$) by the following equation:

$$\rho_{CO_2} = \frac{[CO_2](FS)}{(W)(T)}$$

where $[CO_2]$ is the volume fraction (mL $CO_2 \cdot liter^{-1}$), FS is free space (liter), W is the sample weight (kg) and T is time (h). A completely randomized experimental design was selected to define the treatments effect. Analysis of variance was carried out and significant parameters were subjected to LSD multiple comparison test of means with $P < 0.05$.

RESULTS AND DISCUSSION

Fruits changed color from predominantly green to red seven or 14 days after treatment imposition compared to fruits in their initial condition (Figure 1). Similarly, luminosity was significantly reduced in both, coated and uncoated fruits, regardless of the environment they were maintained when fruits had seven days of storage (Figure 2). Luminosity of fruits maintained for 14 days under controlled environment were significantly affected compared to fruits in their initial condition, regardless of whether they were coated or uncoated (Figure 2). Fruits maintained under uncontrolled environment exhibited a significant reduction in luminosity, although coating had no significant effect; the reduction in average luminosity was due to the fact that some fruits died by the time the measurements were performed, probably because they were maintained in non optimal temperature and relative humidity conditions. The decreased color observed 14 days after storage of fruits under uncontrolled environment (Figure 1) was also due to the dead of fruits that impacted the average estimated and not to a red fruits turning green.

The results revealed that luminosity remained practically constant after 14 days of storage compared with the values obtained seven days earlier when tomatoes were maintained in controlled environment and that coating was not associated with preservation of luminosity. However, it is important to point out that seven days after treatment imposition the mean luminosity of coated fruits under controlled environment was 13.9 % lower than that of

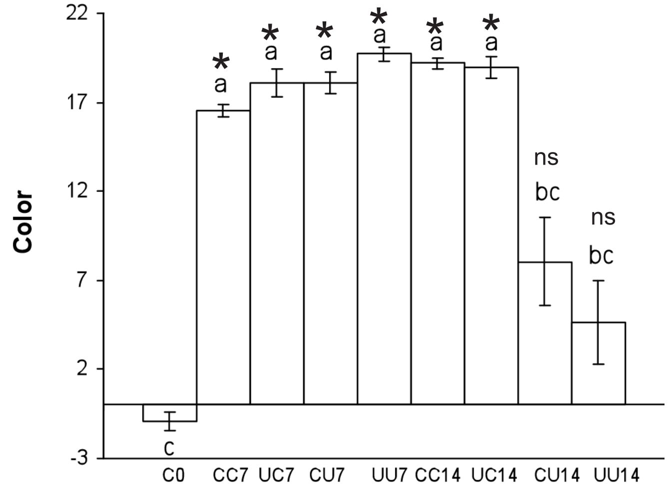

FIGURE 1. **Color of tomato fruits after seven or 14 days of storage treated with or without a coating of polyvinyl acetate. An '*' indicates significant differences compared to the respective control treatment (*P* ≤ 0.05), whereas 'ns' indicates non significant differences according to LSD multiple comparison test. Bars indicate standard error of the mean. UN0 = uncoated fruits in initial conditions; 7 = seven days of storage, 14 = 14 days of storage, C0 = coated fruits in initial conditions; CC = coated fruits in controlled environment (21 °C and 60 % relative humidity); UC = uncoated fruits stored in uncontrolled environment (room temperature); CU = coated fruits stored in uncontrolled environment; UU = uncoated fruit stored in uncontrolled environment. Negative values indicate green color whereas positive values indicate red color.**

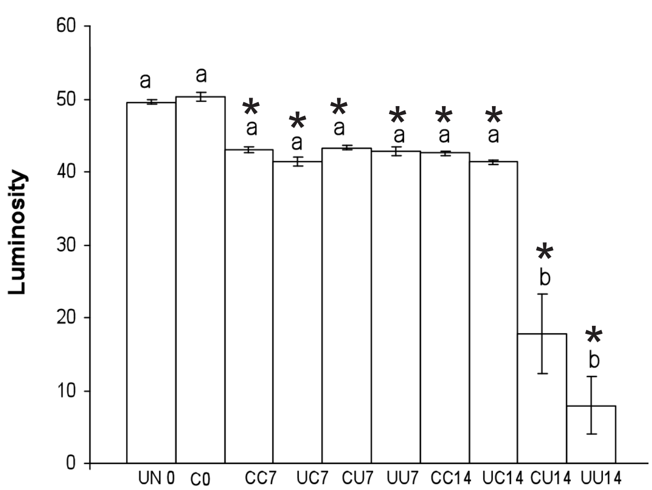

FIGURE 2. **Luminosity of tomato fruits after seven or 14 days of storage treated with or without a coating of polyvinyl acetate. An '*' indicates significant differences compared to the respective control treatment (*P* ≤ 0.05) according to LSD multiple comparison test. Legends as in Figure 1.**

fruits previous to treatment imposition. Uncoated tomatoes under controlled conditions exhibited a luminosity 17.1 % lower than fruits at the beginning and 3.7 % lower luminosity than the fruits coated with PVA. It would be interesting to find out whether these differences are detected by the consumer at the moment of purchase. Data reported by Bertin *et al*. (2001) suggest that this qualitative trait is related to diverse physical and chemical parameters during pre and postharvest. In addition, fruit metabolism during transportation and storage after harvesting can have a significant effect on the light refraction index of tomato fruits (Hurr *et al*., 2005).

Fleshy fruits of many species have a natural external protective barrier of wax that prevents water evaporation through epidermis that results in retarded weight loss. Seven days after experiment initiation, significant differences among environments at which fruits were maintained were detected compared to initial fruit conditions; however, coating of fruits was not able to reduce significantly weight loss (Figure 3). Nonetheless, fruits kept under controlled conditions and coated with PVA showed a significantly lower weight loss compared to that of coated fruits stored under uncontrolled conditions (Figure 3). Uncoated fruits had a slight, but no significant, increase in weight loss compared to coated fruits maintained in either controlled or uncontrolled environment (Figure 3).

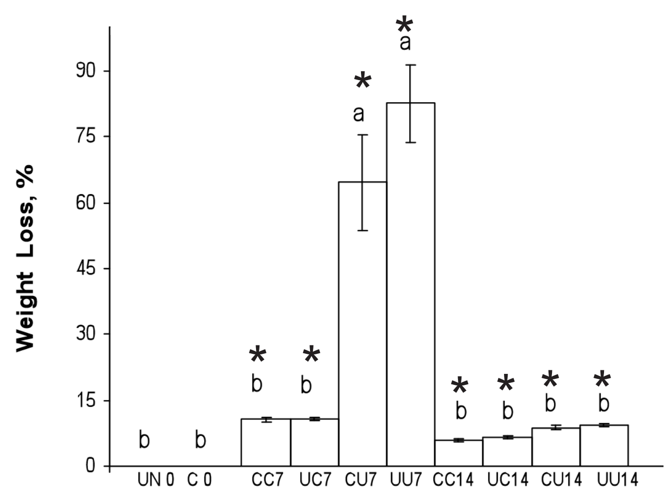

FIGURE 3. **Weight loss of tomato fruits after seven or 14 days of storage treated with or without a coating of polyvinyl acetate. An '*' indicates significant differences compared to the respective control treatment (*P* ≤ 0.05) according to LSD multiple comparison test. Legends as in Figure 1.**

Tomatoes stored during 14 days exhibited no significant effects of coating in weight loss but a significant effect of the environment at which the fruits were exposed was detected (Figure 3). Fruits maintained under uncontrolled environment exhibited higher weight loss than fruits stored in controlled environment. As observed in fruits stored for seven days, coating tomatoes with PVA and stored for 14 days resulted in lower weight loss compared to uncoated fruits when they were maintained in uncontrolled environment (Figure 3). The weight loss of uncoated fruits was expected since coating provides an additional barrier to transpiration and thus, reduced water loss. Uncontrolled environment conditions are conductive to higher weight loss of uncoated fruits because of the higher vapor pressure deficit under such conditions that lead to a larger driving force for water vapor loss from the fruit surface.

Compared to firmness of fruits previous to experiment initiation, PVA-coated tomatoes under controlled conditions did not exhibit significant reductions in fruit firmness when stored for seven or 14 days (Figure 4); however, coated and uncoated fruits showed significant decreases when stored for 14 days under uncontrolled environments (Figure 4). The results suggest that environmental factors such as temperature and relative humidity impacted fruit firmness rather than the polymeric coating by itself. Fruits stored during 14 days showed lower firmness as compared to fruits stored for seven days, regardless of coating or storage conditions, which may be associated to the ripening of fruits and loss of cell wall integrity. Thus, coating with PVA was not effective enough to protect tomatoes from softening during storage, under the experimental conditions used in this research. Other compounds such as the ethylene antagonist 1-MCP can affect fruit firmness since mature-green and breaker stage tomato fruits that were treated with this substance did recover to an acceptable firmness (5-10 N) and exhibited a severely reduced storage life when compared with untreated tomatoes of equal maturity (Hurr *et al*., 2005).

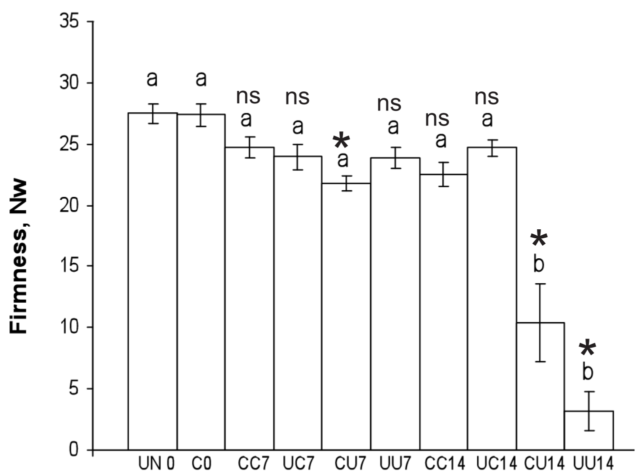

FIGURE 4. Firmness of tomato fruits after seven or 14 days of storage treated with or without a coating of polyvinyl acetate. An '*' indicates significant differences compared to the respective control treatment ($P \leq 0.05$), whereas 'ns' indicates non significant differences according to LSD multiple comparison test. Legends as in Figure 1.

Soluble solids decreased when stored for seven days buy only coated tomatoes under controlled environment exhibited significant reductions (Figure 5) when stored for

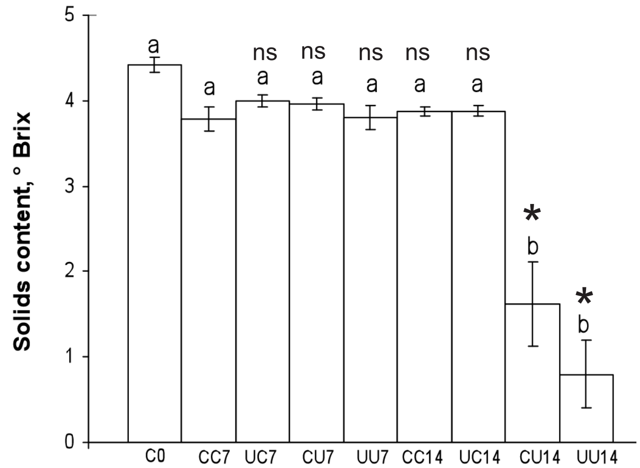

FIGURE 5. Soluble solids (^{0}Brix) of tomato fruits after seven or 14 days of storage treated with or without a coating of polyvinyl acetate. An '*' indicates significant differences compared to the respective control treatment ($P \leq 0.05$), whereas 'ns' indicates non significant differences according to LSD multiple comparison test. Legends as in Figure 1.

14 days; coated and uncoated tomatoes under uncontrolled environment showed significant decrease in soluble solids (Figure 5). These findings agreed with the results reported by Helyes *et al*. (2006).

Vitamin C concentration decreased significantly when fruits were stored for seven or 14 days (Figure 6) under controlled or uncontrolled environments with respect to initial condition. However, neither coating nor environment condition has a significant effect in fruits stored for seven days whereas fruits stored for 14 days under uncontrolled environment exhibited a significant reduction in vitamin

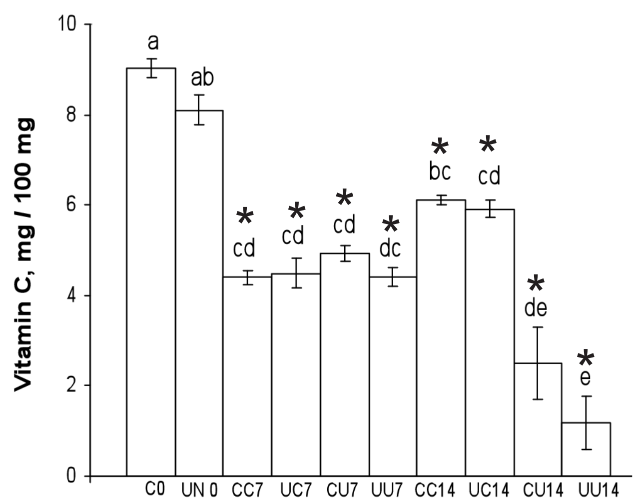

FIGURE 6. Vitamin C of tomato fruits after seven or 14 days of storage treated with or without a coating of polyvinyl acetate. An '*' indicates significant differences compared to the respective control treatment ($P \leq 0.05$) according to LSD multiple comparison test. Legends as in Figure 1.

C concentration compared to fruits stored in controlled conditions and regardless of coating treatment. Similar reports have been published for other horticultural crops, as described by Lee and Kader (2000) that indicate that loss of vitamin C is accelerated by high temperatures and with longer storage time. Our results are in agreement with reports by Sablani *et al*. (2006) that indicate that concentration of vitamin C in tomatoes declined gradually during storage at 4 °C or ambient temperature (25 °C) and with increasing duration of storage time. Chen *et al*. (2000) found similar results at different low (15 °C) and high (28 °C) storage temperatures. Additionally, it has been reported that overripe tomatoes presented lower ascorbic acid content than green tomatoes (Rodríguez *et al*., 2006). Conditions that are favorable for water loss after harvest are also reported to result in a rapid loss of vitamin C, especially in leafy vegetables (Lee and Kader, 2000).

Compared to tomatoes previous to experiment initiation, RR of PVA coated and uncoated fruits seven and 14 days (Figure 7) after treatments started showed significant increases regardless of the environmental condition in which they were stored. Higher RR may be responsible for the reduction in soluble solids reported previously. As for other measurements, coated tomatoes exhibited lower RR than uncoated tomatoes when fruits had seven days of storage; nonetheless, when fruits were stored for 14 days, uncoated fruits exhibited lower RR than coated fruits. After 14 days of storage, respiration rates of tomatoes presented lower RR with respect to fruit stored for seven days. It is well documented that higher CO_2 and lower O_2 concentrations depress respiration of fruits and vegetable during postharvest (Beaudry, 1999); therefore, the lower RR of fruits stored for 14 days may be due to the increasing concentration of CO_2, and thus the lower O_2 concentration, byproduct and substrate of the respiratory process, respectively, in the environment. Coating fruits with the PVA polymer surely modified the atmosphere surrounding the fruit, and thus concentration of gases was probably modified; since RR was higher at least for seven days (Figure 7) it is possible that CO_2 concentration increased whereas O_2 concentration decreased underneath the coating since the PVA acted as a barrier for gases diffusion. The consequence of higher CO_2 and lower O_2 was also probably related to the decrease in RR in coated fruits compared to uncoated fruits. Higher CO_2 and lower O_2 concentrations also inhibit ethylene biosynthesis by suppressing ACCsynthase at RNA level (Gorny and Kader, 1997), retarding the maturity process of fruits. Ethylene has been associated to the synthesis of enzymes, such as polygalacturanase, that degrade middle lamella and primary cell wall in tomato (Crookes and Grierson, 1983) that may explain the significant decrease in fruit firmness after 14 days of storage under uncontrolled environment.

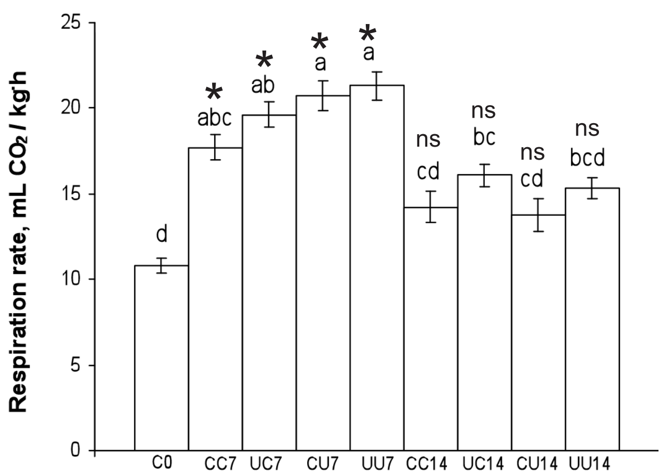

FIGURE 7. Respiration rate of tomato fruits after seven or 14 days of storage treated with or without a coating of polyvinyl acetate. An '*' indicates significant differences compared to the respective control treatment ($P \leq 0.05$), whereas 'ns' indicates non significant differences according to LSD multiple comparison test. Legends as in Figure 1.

In spite of the non significant effect of fruit coating, RR results have important physiological and storage life implications because the polymeric coating noticeably reduced the metabolism of tomato fruits. Further, the results also imply noteworthy commercial consequences because reducing respiration during shipping and storage of fruits and vegetables increases shelf life and preserves fruit quality (Malacrida *et al*., 2006). Respiration is essential for growth, preservation and carbon balance on all plant cells; in tomatoes as in other fruits, respiration rate indicates ripening rate under either controlled or natural conditions (Lee *et al*., 2007). The higher reduction in vitamin C detected in the present experiment may also be due to the reduced O_2 and increased CO_2 concentration after 14 days of storage, as suggested by Lee and Kader (2000).

CONCLUSIONS

No significant effects due to coating treatment were attained in the present experiment. It is likely that PVA film thickness in this work was not enough to influence more effectively on the ripeness process of tomato fruits. Another explanation is the non uniform application of the PVA film around the fruits, preventing consistent results. Therefore, we conclude that more research work is needed to consider these facts and control other factors that might be important in fruit ripening such as the molecular weight of the PVA.

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